Banana and Plantain

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Scientific Name and Introduction: *Musa acuminata* and *Musa balbisiana***,** most cultivars of edible bananas and plantains derive from these two members of the family *Musaceae* (Simmonds and Shepherd, 1955). Before the 1940's the cultivar 'Gros Michel' dominated the international banana trade, until it succumbed to *Fusarium* wilt (Panama disease). Since the 1940's the trade has adopted cultivars of the Cavendish subgroup. Bananas are eaten mainly raw as a dessert fruit because they are sweet when ripe. Plantains, also referred to as 'cooking' bananas, are much starchier and can be eaten either ripe or unripe. The edible cultivars of bananas and plantains are seedless. The two obvious tissues that constitute the fruit are the pulp and the peel. The peel is the ovary wall. The pulp originates from cell division of the innermost layers of the pericarp. The growth of the peel begins to slow down as the fruit matures but the growth of the pulp continues, consequently peel splitting often occurs in very mature green fruit (Turner, 1997).

Quality Characteristics and Criteria: A premium quality banana is very clean (free from defects such as scars, physical damage, insect injury, and latex staining), free from decay, has an adequate finger length and diameter, does not have excess curvature, and upon ripening has the desired uniform bright yellow color and sensory attributes in flavor (sweetness, acidity) and aroma. Attributes are defined by consumer preference.

Horticultural Maturity Indices: Commercially, bananas and plantains must be harvested while mature green, and transported to destination markets where they are ripened under controlled conditions (bananas), and controlled or natural conditions (plantains). Fruits ripened on the plant often split and have poor texture. Harvest time represents a compromise between leaving the fruit on the plant long enough to maximize yield, but harvesting it soon enough so that sufficient green life remains to market fruit with acceptable quality. The stage of maturity for harvesting the fruit depends on the market for which is intended and is determined in terms of the marketable life required. Plantains tend to mature more prematurely than bananas when harvested at the same age. One very useful criteria for harvesting fruit that is used commercially is age of the bunch after emergence from the pseudostem (emergence can be defined as the day on which the first complete hand of fruit is visible). Because bananas are growing rapidly when harvested, fruit size (finger diameter, and length), and finger fullness (angularity) are suitable measures of harvest maturity. At a given age, the maturity of hands in a stem varies, those hands at the proximal end of the stem being more mature than those at the distal end. An estimate of maturity of the entire stem is then assessed using the second hand from the proximal end. It is usual to measure length/diameter (caliper grade or calibration) of the middle finger on outer whorls of the second hand on the stem before running fruit through packing plant processes.

Grades, Sizes and Packaging: Minimum acceptable size (length and diameter) grade standards for export markets vary depending on banana and plantain cultivar and market specifications. Hands, clusters, or single fingers not meeting these fresh market grades are used for processing products or discarded. Bananas are packed in corrugated fiberboard boxes as whole hands, clusters or individual fingers holding an average weight, for premium fruit, between 13 and 18 kg (28 to 40 lb) depending on market preference. Plantains are packed as individual fingers in 18 kg boxes. Most exporters use polyethylene film liners and paper pads to reduce moisture loss and provide protection to fruit from physical damage during handling and transport.

Pre-Cooling Conditions: Pre-cooling of bananas or plantains is not generally done. Adequate cooling is not initiated until fruit are loaded into containers or cargo holds onboard ships.

Optimum Storage Conditions: Optimum temperatures for storage and holding of green bananas are 13.3 to 14.4 ºC (56 to 58 ºF) (Thompson and Burden, 1995). Some banana cultivars can be handled at 12.8 ºC (55 ºF). Because marketing quality standards are more relaxed for plantains, and plantains are more prone to premature ripening during transit and storage, it is recommended that green plantains be held between 8.9 to 11.7 ºC (48 to 53 ºF). Plantains grown during the warmer months tend to attain physiological maturity faster than fruit grown during the Winter months, consequently green life potential varies during the year. Optimum RH for holding and transport fruit is 90 to 95%. Holding of ripe fruit should be kept to a minimum.

Controlled Atmosphere (CA) Considerations: Bananas and plantains respond well to CA. CA is used commercially during ocean transport of green bananas. Modified atmosphere packaging using polyethylene bags (banavac) is used for both bananas and plantains, but plantain are physiologically more active than bananas and have higher respiration rates and could exhaust O_2 more rapidly than bananas. Optimum gas levels for most cultivars range between 2 to 5% O_2 and 2 to 5% CO_2 (Bishop, 1990; Kader, 1992,1993,1997). Main benefits of controlled atmospheres include delaying of ripening, reduction of crown rot incidence, and a much fresher condition (latex flowing through the vascular tissues) upon arrival at destination. Shelf-life can potentially be extended 2- to 3-fold by optimum CA. O_2 levels below 1 to 1.5 % may cause grayish or brown peel discoloration, failure to ripen properly, and off-flavor (Kader, 1992; Kader, 1993; Kader, 1997). CO_2 levels greater than about 6 to 8% may cause pulp to soften while the peel is still green, and may confer undesirable texture and flavor (Wei and Thompson, 1993; Kader, 1993; Kader, 1997). Ripe fruit can tolerate higher levels of CO_2. The beneficial and detrimental effects of reduced O_2 and/or elevated CO_2 are temperature and time-of-exposure dependent. Removal of ethylene gas can have an additional benefit on extending green-life of bananas and plantains, under both ambient and modified atmosphere conditions (Scott et al., 1970; Liu, 1976; Scott, 1977; Turner, 1997). CO_2 inhibits the effect of ethylene on ripening, and higher levels of O_2 than those under CA are necessary for adequate ripening. Thus, bananas held under CA should be ventilated with fresh air for at least 18 to 24 h before ripening (gassing with ethylene) is initiated. An under-peel discoloration that resembles chilling injury has been observed on green bananas when transported long distance under controlled atmospheres conditions at below 14 ºC (57.5 ºF), this disorder has also been associated with high temperatures of 33 to 35 ºC (91 to 95 ºF) in the field (Stover and Simmonds, 1987).

Retail Outlet Display Considerations: Fruit should be displayed at retail in non-refrigerated areas in the produce section. Existing refrigerated shelf space in supermarkets normally is below the minimum safe temperature for bananas and plantains and chilling injury can still occur in ripe fruit. Displaying surfaces should be cushioned in order to avoid physical damage to the fruit.

Chilling Sensitivity: Chilling injury is an important disorder of bananas and plantains. Both green and ripe fruit are susceptible, with green fruit being slightly more sensitive than ripe fruit. Chilling injury results from exposing fruit to temperatures below about 13 ºC (56 ºF) for a few hours to a few days, depending on cultivar, maturity, condition of the fruit, temperature, and duration of exposure (Stover, 1972; John and Marchal, 1995; Turner, 1997). Chilling injury is mainly a peel disorder. Symptoms include sub-epidermal discoloration visible as brown to black streaks in a longitudinal cut, a dull or grayish (smokey) cast on ripe fruit, failure to ripen, and in severe cases the peel turns dark brown or black, and even the flesh can turn brown and develop an off taste (John and Marchal, 1995; Turner, 1997). Chilled fruit are more sensitive to mechanical injury. Ripe fruit, if chilled, turn dull brown when later exposed to higher temperatures and are very susceptible to handling marks; the slightest pressure causes discoloration. Inflicted chill in green or ripe fruit may not become apparent until 18 to 24 h after actual damage has occurred.

Ethylene Production and Sensitivity: Bananas and plantains are sensitive to physiological levels of ethylene as low as 0.3 to 0.5 µL L^{-1} if the O_2 and CO_2 levels are similar to those found in outside fresh air (Peacock, 1972). The three main factors affecting response to external ethylene are: fruit maturity; time from harvest when ethylene exposure began; and the length of exposure to ethylene.

Temperature	µL C_2H_4 kg^{-1} h^{-1}
13 ºC	0.04 to 2.0
15 ºC	0.15 to 5.0
18 ºC	0.20 to 8.0
20 ºC	0.30 to 10.0

Lower values in the range are for mature-green fruit, and higher values are for ripening fruit. Data modified from Kader (1998).

Controlled Ripening: Mature bananas left to ripen naturally will eventually soften but the change in color will not be uniform and the peel will be dull, pale yellow and unattractive. In order for the fruit to attain a bright yellow peel color, a firm pulp texture, and good flavor, bananas are ripened by releasing ethylene into a sealed chamber or room and at controlled temperature and RH. Plantains are being ripened by this controlled method in most markets but in some they still rely on natural ripening. Immediately after harvest bananas do not respond to ethylene treatment or, in the best scenario will initiate ripening but will never attain the characteristic bright yellow coloration. One main reason for controlled ripening is to provide retailers and wholesalers with fruit at a stage of ripeness desired by consumers.

Generally, very low concentrations of ethylene are sufficient to ripen the fruit, ie., 10 to 50 µL L^{-1}, (Thompson and Seymour, 1982). In commercial practice however, 1000 µL L^{-1} is commonly used to ensure uniform ripening. This is partly because many ripening rooms are not fully gas tight and the concentration may be rapidly reduced through leakage. Most commercial cultivars of bananas and plantains require exposure to ethylene for 24 to 48 h at 14.4 to 18 ºC (58 to 64 ºF) (Thompson and Burden, 1995; Robinson, 1996). However, temperatures of up to 20 ºC (68 ºF) are sometimes necessary for bananas (Thompson and Burden, 1995). Optimum RH levels during ripening are 90 to 95% (after coloring is underway RH should be reduced to 85% to prevent peel splitting). High RH requirements for proper ripening can be attained when the fruit is being packed in partially-sealed polyethylene liners. Exposure of ripe bananas or plantains to temperatures higher than those in the ripening range hastens softening and decay, weakens the neck, can cause splitting of the peel, and may cause poor color development.

The color of the peel is used as an indicator of ripening. A scale of 1 to 7 is convenient where 1 is dark green, 2 is light green, 3 is more green than yellow, 4 is more yellow than green, 5 is yellow with green tips, 6 is fully yellow, and 7 is flecking (Kader, 1992). Room ventilation after gassing with ethylene is essential to keep $CO_2 < 1\%$ and avoid its effects on delaying ethylene action. Use of a forced-air system (pressurized) in ripening rooms assures more uniform cooling or warming of the fruit as needed and more uniform ethylene concentrations throughout the ripening. When ripening is done in non-pressurized conventional rooms, open stacking of boxes is essential to allow adequate air circulation for uniform ripening. Many stacking patterns are used, the best pattern to be used depends upon pallet sizes and ripening facilities. Because heat rises, the amount of box top area exposed is most important for preventing heat build-up in the stack and controlling pulp temperature during ripening. Bananas are usually ripened to color stage 3 to 4 before delivery to distribution centers, retailers or wholesalers.

Within certain limits, the period required for ripening bananas can be shortened or extended to meet trade requirements by adjusting the temperature. Under average conditions, depending on initial temperatures chosen and condition of the fruit, the ripening cycle can be as short as 4 days (> 18 ºC) or may be extended to 8 to10 days (at 14 ºC). If initial ripening temperatures are too high (> 25 ºC), the pulp will soften but the peel will remain green (a condition described as 'cooked' or 'boiled' fruit) (Robinson, 1996; Turner, 1997). Uneven ripening can be caused by low temperatures and insufficient ethylene. Ripening rates and characteristics of the fruit vary to some extent between lots depending on cultivar, country of origin, weather conditions during the growing of the fruit, temperatures during handling and transit, and maturity of the fruit. Hard-green fruit (less full), will take longer to ripen than more advanced and full fruit.

Respiration Rates:

Temperature	mg CO_2 kg^{-1} h^{-1}
13 ºC	20 to 80
15 ºC	26 to 140
18 ºC	32 to 200
20 ºC	40 to 280

The lower value of the range is for mature-green fruit, and the higher value is for ripening fruit. Data were modified from Kader, 1998. To get mL kg^{-1} h^{-1}, divide the mg kg^{-1} h^{-1} rate by 2.0 at 0 °C (32 °F), 1.9 at 10 °C (50 °F), and 1.8 at 20 °C (68 °F). To calculate heat production, multiply mg kg^{-1} h^{-1} by 220 to get BTU per ton per day or by 61 to get kcal per metric ton per day.

Physiological Disorders: A condition known as 'maturity bronzing' or 'maturity stain' has been observed in Australia and Central America at certain times during the year, 20 to 30 days before harvest. (Stover and Simmonds, 1987). The fruit is unacceptable for market although eating quality is unaffected. This disorder has been associated with water deficits at bunch emergence during rapid fruit growth under very humid and hot conditions (Daniells et al., 1987; Williams et al., 1989, 1990). If bananas and plantains are exposed to temperatures above 30 to 35 ºC, ripening can be irreversibly inhibited (high temperature injury) .

Postharvest Pathology: The main postharvest pathological diseases of bananas and plantains are crown rot, a disease complex caused by several fungi (*Colletotrichum musae, Fusarium semitectum, Fusarium pallidoroseum, Lasiodiplodia theobromae, Botryodiplodia theobroame, Ceratocystis paradoxa, Verticillium sp,. Acremonium sp., Curvularia sp*.) and anthracnose (*Colletotrichum musae*) (Stover, 1972; Wardlaw, 1972; Stover and Simmonds, 1987; Snowdon, 1990; Jeger et al., 1995). Anthracnose is a latent infection that occurs in the plantation, although it can appear on green fruit is more apparent in ripening fruit as numerous small dark circular spots. Crown rot organisms normally enter after harvest, usually as a result of mechanical injury to the fruit. Other diseases that from time to time become important locally include: stem end rot (*Lasiodiplodia theobromae / Thielaviopsis paradoxa*) where the invaded flesh becomes brown, soft and water-soaked; cigar end rot (*Verticillium theobromae / Trachysphaera fructigena*) where the rotted tip of the finger is dry and appears similar to the ash of a cigar (Stover, 1972; Wardlaw, 1972; Stover and Simmonds, 1987; Snowdon, 1990; Jeger, et al. 1995). Sigatoka disease of bananas is caused by *Mycosphaerella sp.* and has been reported in most banana/plantain producing countries (Snowdon, 1990). The potential of this fungal disease is such that a flourishing banana industry can be destroyed within a few years. Fruit symptoms include premature ripening, buff-colored pulp, and increased susceptibility to chilling injury. Preventive and control measures to reduce decay incidence begin with strict sanitation in plantation and packing plant, postharvest treatment with systemic fungicides, minimize mechanical damage during handling, prompt cooling of fruit to lowest safe temperature, and expedite transport to final destination.

Quarantine Issues: None

Suitability as Fresh-Cut Product: Bananas and plantains are not good candidates for fresh-cut processing because of their very high oxidation and browning potential (John and Marchal, 1995).

Special Considerations: Mechanical damage in bananas and plantains take several forms that vary in importance depending upon the perceptions of consumers. Banana peel is very sensitive to mechanical damage. Export markets for bananas require a blemish-free fruit, although requirements are a bit more relaxed for plantains. Great care during handling is needed at all times. Bruising of the pulp is undesirable and cannot always be detected from damage to the peel (Akkaravessapong, 1986). RH levels < 85 to 90% accentuate symptoms of mechanical damage.

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